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Breakthrough

UNIVERSITY OF SOUTH CAROLINA

RESEARCH & HEALTH SCIENCES



Summer 2008

The University of South Carolina is building a green-collar culture in the development of alternative energy and future fuels.



Future fuels

Not to diminish American car drivers' pain at the pump, but the extravagant price we pay these days for a gallon of gasoline is only one of many woes besetting the global energy market.

Blame the unbending laws of supply and demand if you like—and it's true that the large populations of India, China, and other nations are joining the already ravenous U.S. thirst for gasoline and other forms of energy. But even if energy supplies were unlimited, the conjoined threats of greenhouse gas emissions and global warming would force us to consider alternative energy sources.

Can we have our cake—plentiful energy—and use it, too, without further deteriorating the environment? Even more to the point, what can energy research do to decrease American dependence on foreign oil, make electricity without making more greenhouse gas, and find viable ways to tap into renewable energy sources?

Our dean of the College of Engineering and Computing, Michael Amiridis, puts it succinctly: "The energy problems we face are complex, and the solutions are going to be equally complex—there won't be one magic bullet."

That's why we're focusing on several areas: hydrogen, PEM, and solid-oxide fuel cells, next-generation battery development, nuclear energy, photovoltaic cells, sustainable carbon usage, biomass, and energy conservation and efficiency. All of these are interconnected and could be part of the overall solution.

The University of South Carolina has solid credentials in energy research and is committed to becoming even stronger. South Carolina is home of the nation's only industry/university cooperative fuel cell research center, sponsored by the National Science Foundation and industry partners, and the Strategic Hydrogen Alliance will hold its national conference here in 2009. The University also has one of the world's top photonics research labs, whose research has yielded important applications in energy-efficient lighting.

In addition, the University has received a multi-million dollar research award to study clean coal technologies and will have recruited nearly a dozen new energy scientists by year's end.

Innovative energy research is crucial not only to America's sustainable economic development and well being but also to the ecological future of the planet. Scientists at the University of South Carolina aim to be at the forefront in that important work.

A handwritten signature in black ink that reads "H. Pastides".

Harris Pastides

Vice President for Research and Health Sciences
University of South Carolina

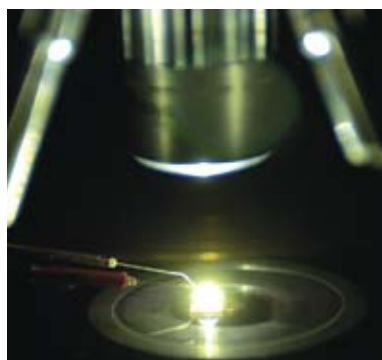
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Engineers are teaching an old technology new tricks and lighting things up with less electricity.



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A new research center will explore ways to make black coal a green energy source.



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Energy forums

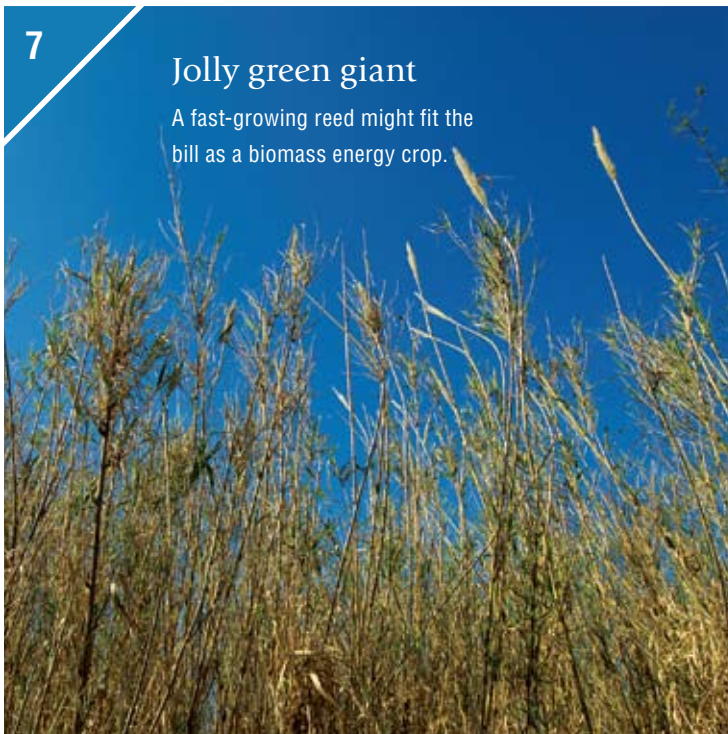
A series of energy forums could help citizens understand better the nation's energy options.



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Jolly green giant

A fast-growing reed might fit the bill as a biomass energy crop.



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New look at nuclear

University of South Carolina researchers look ahead to next-generation reactor fuels and hydrogen conversion.

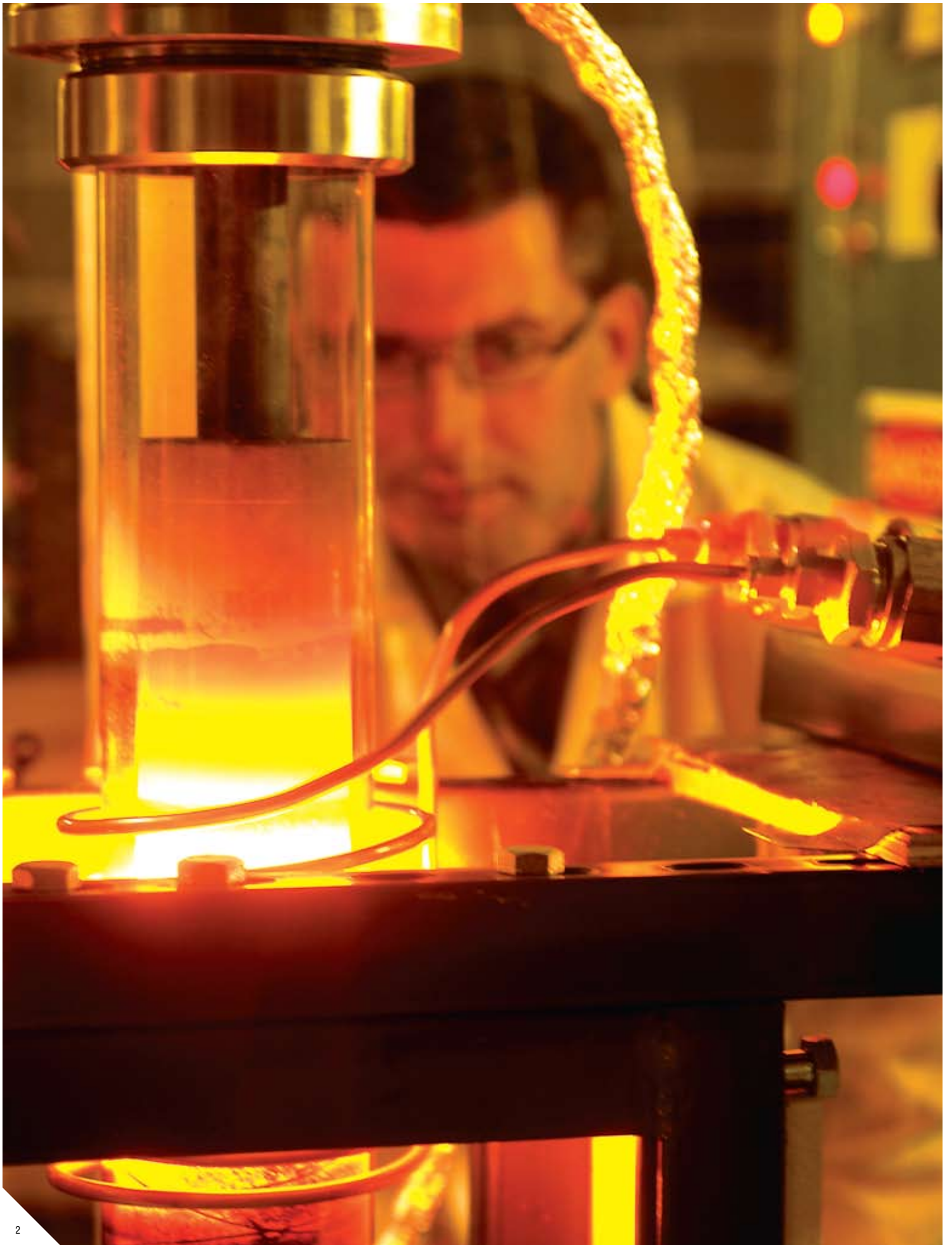


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World-class research in fuel cells

University scientists are focused on designing affordable, highly efficient hydrogen fuel cells.





New look at nuclear

Nuclear energy is making a comeback, and University of South Carolina researchers are studying ways to make it more efficient and how to tap into its potential to make hydrogen gas.

South Carolina was the first state in the Southeast to have an electricity-producing nuclear power plant—a tiny 17-megawatt reactor that began generating in 1963.

Travis Knight, opposite page, a mechanical engineering professor at the University of South Carolina, is continuing that pioneering spirit with a research program focused on developing fuel for a future generation of nuclear reactors. He's also the first faculty member recruited in the College of Engineering and Computing for a nuclear engineering program offering graduate degrees and an undergraduate minor. The college plans to recruit three more faculty members for the program.

"There is the potential for 30 new plants to be built in the next decade so there will be a great need for more master's- and Ph.D.-prepared professionals," Knight said. "The industry is also looking down the road to a new generation of high-temperature nuclear reactors, and that will require new types of fuel."

South Carolina is well positioned for its nuclear engineering endeavor. Savannah River National Laboratory, a nearby federal nuclear facility with deep experience in nuclear research, is one of the University's long-time research partners. Westinghouse, another research partner, operates a nuclear fuel processing plant just a few miles from the College of Engineering and Computing.

Knight has a three-year, \$450,000 grant from the Department of Energy (DOE) to investigate mixed-carbide fuels for use in gas-cooled fast reactors. Conventional reactors use uranium dioxide to create heat and generate electricity. Future reactors might use recycled fuels that are coated with zirconium carbide, a highly conductive material that would be more efficient than ordinary uranium dioxide. Another three-year, \$300,000 project has Carolina collaborating with Nuclear Fuel Services, which fabricates fuel for the U.S. Navy, on the coated particle fuel for high-temperature reactors.

"South Africa, Japan, and China are building high-temperature reactors, and there are plans to use gas coolant and composite fuels, but no one is yet building a gas-cooled fast reactor," Knight said.

What's the difference? Unlike conventional reactors, which slow down neutrons with water, the so-called fast reactor does not slow them down and uses fuels unacceptable to conventional reactors. Because of its unconventional fuel, high operating temperature, and operating efficiency, a gas-cooled fast reactor would create smaller amounts of waste products.

Even better, the so-called Generation 4 reactors will be ideally suited to cracking the hydrogen from various compounds to create hydrogen gas for a hydrogen economy.

"The only way for a hydrogen economy to make sense is having the ability to make hydrogen efficiently," said **John Weidner**, a chemical engineering professor in the College of Computing and Engineering who is using DOE grants to study hydrogen production from nuclear energy. "If you expend too much energy to extract hydrogen, there's not much point, right? So we're studying different thermo-chemical cycles that make use of the high heat generated by next-generation reactors to crack hydrogen from water," Weidner said.

Nuclear plants could churn out electricity during the day when homes and businesses use it most, then produce electricity at night to run the hydrogen extraction process. The stored hydrogen could then power large fuel cells or refuel hydrogen-powered cars.

One hydrogen extraction process, first developed in the 1970s by Westinghouse, decomposes sulfuric acid at high temperature to release hydrogen. The sulfuric acid is then regenerated in an electrochemical reactor (i.e., electrolyzer), which also produces hydrogen. The overall process breaks water into hydrogen and oxygen. The sulfuric acid is recycled and never released. Weidner is investigating ways to make these electrolyzers more efficient.

Chemical engineering research professor **Tom Davis** is applying his expertise in salt separation to improve another type of thermo-chemical cycling involving the internal recycle of copper chloride.

"The first oil crisis in the 1970s got these programs going, and then they were dropped," Weidner said. "Now, concerns about oil supplies and global warming are driving us faster toward a hydrogen economy that would have a much smaller carbon footprint than our current energy infrastructure."

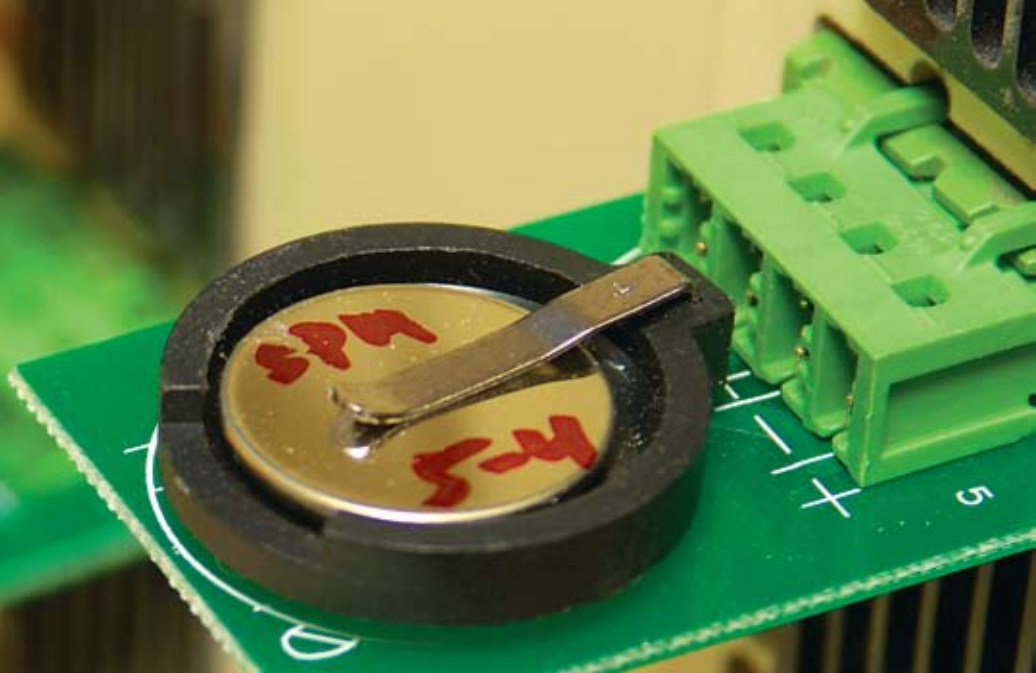
Francis Gadala-Maria, another chemical engineering professor, is South Carolina's point person in a consortium with Tulane and Penn State universities to evaluate the merits of these and other thermochemical cycles for large-scale, efficient hydrogen production from nuclear energy. ■

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Branko Popov



In search of the ideal battery

At the University of South Carolina, researchers are jump-starting battery technology.

Since 1800, when the Italian physicist Alessandro Volta built his voltaic pile, the indispensable battery has undergone many improvements. Today we see a variety of batteries—alkaline, lead-acid, nickel-cadmium, nickel-metal hydride (Ni-MH), and lithium-ion (Li-ion), among others—used in numerous applications. But battery technology has not yet reached its full potential. Researchers with the University of South Carolina's Center for Electrochemical Engineering (CEE), however, are making strides in improving several kinds of batteries.

Challenges in battery research

Batteries are generally classified as primary or secondary: Primary batteries are those that cannot be reused once they're expended; secondary batteries can be recharged and used many times. The batteries commonly found in flashlights, for example, are of the primary type, while the secondary type can be found in cars, portable power tools, and cell phones, among many other applications. The CEE focuses on the secondary type, particularly Ni-MH and Li-ion batteries. The researchers are developing new materials for cathodes and anodes for those batteries, and they're studying the charge-discharge behavior, utilization, and capacity fade, which is a measure of how quickly the current-output capability of a battery dissipates.

Cost is one consideration in the CEE's battery research. Li-ion batteries, for example, offer a high power density compared to other battery systems, but only because they're engineered using an expensive material. "More importantly," Popov said, "their cycle life [the number of discharges a battery can provide] is limited, which also contributes to their

high cost per kilowatt produced. Those batteries should cost much less than today's \$30 per kilowatt." Among other accomplishments, the CEE has developed high-performance anode materials for Ni-MH batteries, resulting in a higher capacity, a longer cycle life, a low self-discharge, a uniform operation at high temperatures, and corrosion resistance.

Another major consideration is the environmental impact of discarded batteries. The toxic materials contained in most batteries, if not disposed of properly, could leach into groundwater and present serious health and environmental problems. Clearly, the researchers face a formidable challenge: to find that ideal but delicate balance among the parts and characteristics of the "simple" battery. The various materials must be less expensive, but they must also contribute toward a more efficient, longer lasting, more environmentally friendly battery.

Outside interest

The CEE's research has sparked interest from the U.S. Department of Energy. The department's Office of Basic Energy Sciences (BES), for example, has provided more than one million dollars in funding

The largest battery in the world is located in Fairbanks, Alaska; weighs 2.8 million pounds; and can provide 40 megawatts of electricity for up to seven minutes.

"The ideal battery should be very cheap, have a long cycle life, and be environmentally friendly," said **Branko Popov**, Carolina Distinguished Professor, director of the CEE, and a researcher at the University's Center for Fuel Cells. "Today's batteries do not satisfy any of those requirements."

toward the center's research into the cause of failure of Ni-MH and Li-ion batteries. Popov and his team were the first to show that the failure of those batteries arises from the increase in resistance at both electrodes, particularly the cathode.

The CEE has also worked with Sandia National Laboratory and with St. Jude Medical. For a NASA EPSCoR (Experimental Program to Stimulate Competitive Research) partnership program in 2006, Popov's group developed a mathematical model for predicting the irreversible capacity fade of Li-ion batteries.

The future of batteries

Will hydrogen fuel cells eventually render batteries obsolete? Current fuel-cell technology still has room for improvement in such areas as cost, hydrogen production, hydrogen storage, cathode efficiency, stability, and durability, according to Popov. When those issues are resolved, fuel cells, for most applications, will be better suited than batteries. "Currently, this is not the case," he said. "Today, batteries are the storage system of choice."

The automobile industry, for example, is switching from hybrid vehicles, which rely on batteries and conventional fuel for propulsion, to completely electric cars. "By 2010, we'll be driving electric cars powered by lithium-ion batteries," Popov said.

Popov is joined by **Ralph White**, professor of chemical engineering and a distinguished scientist, and **John Weidner**, professor of chemical engineering. "These two worldwide experts are performing research in the area of optimizing different battery chemistries or optimizing performance through developing mathematical models," Popov said. "Together they help set us apart from the rest."

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On the trail of the missing CO₂

Research at the Belle W. Baruch Institute for Marine and Coastal Sciences explores a carbon mystery.

An essential component of all forms of life, carbon undergoes a continuous recycling process known as "carbon cycling" as it moves between its major reservoirs—the atmosphere, vegetation, earth, and oceans.

It's an element that readily forms compounds with other elements, but it cannot be created or destroyed. So the total quantity of carbon stays constant, but its allocation among the individual reservoirs can vary. And its growing presence in the atmosphere—in the form of carbon dioxide, or CO₂—enhances the greenhouse effect, which results in global warming.

At the University's Belle W. Baruch Institute for Marine and Coastal Sciences, director **Jim Morris** pays particular attention to how carbon is distributed throughout the cycle. "I'm interested in the global-scale questions," he said, "such as what's regulating the concentration of CO₂ in the atmosphere."

That concentration isn't increasing as fast as we might project based on the combustion of fossil fuels. In fact, we're burning about twice as much carbon—in the form of fossil fuels—than is accumulating in the atmosphere. The other half is going elsewhere: some into the ocean, and some into vegetation.

"What happens to the part going into vegetation is a bit of a mystery right now," Morris said. "That's where my research interests lie."

We all learned in school that plants take in CO₂ and release oxygen through the process of photosynthesis. In other words, plants act as a CO₂ sink, or "absorber." Precise measurements of the atmosphere show that the earth's surface does actually serve as a sink for carbon. But, Morris said, a careful inventory of the world's vegetation, along with the organic carbon in the soil, would suggest that the terrestrial landscape might actually be a source of CO₂ in the atmosphere. The reason is deforestation, which leads to a net decrease in the stock of carbon on the earth's surface.

"So how can you reconcile these measurements?" Morris asked. "One finding would suggest that total vegetation is a source, and the other would suggest it's a sink." He believes the carbon might be entering the vegetation, but it doesn't stay there. Mounting evidence supports the idea that carbon moves from the vegetation and soil into rivers and eventually into the oceans. "That's a good thing," he said, "because it provides another avenue for keeping CO₂ out of the atmosphere."





Jolly green giant

A plant genetics researcher champions the giant reed for biofuel.

Fifty years ago, a young Hungarian boy set out in search of a cane pole for fishing. What he found—a tall, bamboo-like plant called the giant reed (*Arundo donax*)—could become the next big thing in 21st-century biomass research.

Laszlo Marton, opposite page, is now a biological sciences professor at the University of South Carolina who pioneered genetic manipulation techniques with plants while still in his native Hungary in the 1970s. He put those research skills to work at South Carolina by tweaking the genome of ordinary marsh grass to transform that plant into a natural vacuum cleaner for heavy metal pollutants in tainted wetlands.

Now he's turned his attention to *Arundo*, the "fishing pole plant" from his youth, to learn more about its ability to absorb toxic organic compounds and its potential as a biomass fuel. It's the latter quality that is particularly intriguing.

"*Arundo* is the ultimate environmental remediation plant—it was planted behind outhouses for centuries because of its ability to absorb contaminants in soggy soil," Marton said. "But it's also a plant scientist's dream when it comes to its potential for biomass."

Biomass is organic plant material that can replace coal or natural gas in a generating plant to make electricity. So long as the biomass is continually replanted, the carbon cycle remains essentially neutral: burned biomass releases carbon, but green biomass captures carbon as it grows.

To be effective, biomass must have high heat value and low requirements for growth, and in those respects, *Arundo* excels. The plant, which originated near India, now grows among the southern tier of the United States from Virginia to California.

"*Arundo* has the same heat value as good-quality hardwood and is better than switch grass or sugar cane as a biofuel," Marton said. "*Arundo* is full of alkaloids so insects hate it and other plants can't compete with it, so herbicides and pesticides aren't necessary to grow it. It grows 10 meters tall in a year with little nitrogen, produces 40 tons of biomass per acre, and it doesn't have to be replanted—you harvest it with standard equipment and it grows back from the roots."

Even better, *Arundo* isn't sexually regenerated, which makes genetic manipulation easier. Marton envisions growing the plant as a micro-pharmaceutical factory that could produce insulin or some other product, then use the dried plant stalk for biofuel.

Marton has patented a procedure for propagating *Arundo* from single plant cells—similar to research with mammalian stem cells. His research has attracted interest from several companies, and he hopes to establish a consortium to further the research while commercial applications begin. One company wants to capitalize on Marton's work by planting 20,000 acres of *Arundo* in the southern U.S. or the Caribbean, which would demonstrate *Arundo*'s large-scale potential and generate licensing revenues and royalties for the University.

How much *Arundo* would be needed to power an electric generating plant? Based on average rainfall and plant growth, Marton estimates that 10,000 hectares (imagine a square six miles-by-six miles in size) would supply enough energy to power a 120 megawatt power plant.

What's best is that *Arundo* is not a food crop and can grow on marginal land, food crops wouldn't be sacrificed to make room for it.

The University of South Carolina's new biomass energy facility operates with forest waste (wood chips) as its primary biofuel, but plant operators have discussed with Marton the possibility of experimenting with *Arundo* to see how it compares with the more traditional wood chips. A small plot of *Arundo* is growing near the plant; if the testing goes well, more acreage could be planted to supply more of the plant's biofuel needs.

"One more thing about *Arundo*. It's long lived. I went back last year to the place in Hungary where I cut that fishing pole. The *Arundo* is still growing," Marton said. ■

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Going green

The University of South Carolina's \$19 million biomass energy facility was completed in 2007 as part of a multi-year energy performance contract with Johnson Controls, an international energy management firm.

In addition to conducting a campus-wide energy audit and overseeing infrastructural improvements in lighting, steam lines, and electrical utilities, Johnson Controls proposed the biomass facility as an innovative and long-term solution to the University's rising energy costs.

The biomass energy facility brings a number of significant benefits to the University, including:

- annual energy cost savings of \$2 million or more
- reduced greenhouse gas emissions
- stable and predictable energy costs
- use of renewable biofuels that are in abundant supply in South Carolina

Unlike traditional biomass energy plants that incinerate biomass materials (forest or agricultural waste), the University's biomass facility uses a next-generation gasification process that superheats rather than burns the biofuel. In this facility, superheated wood chips release gas that is ignited to produce steam, which is used to heat the campus and produce electricity. This process results in fewer particulate emissions than traditional biomass plants.

The plant is expected to supply nearly 75 percent of the University's demand for steam (used for heating and hot water) and enough electricity to power the equivalent of 1,500 homes.

In addition to providing a source of clean and cost-efficient energy for the campus, the biomass energy facility is serving as a teaching tool for the University's College of Engineering and Computing. A technology-equipped classroom is incorporated into the facility and will be used for classes in a number of engineering disciplines.

Jeff Morehouse, a Carolina mechanical engineering professor, provided technical assistance throughout the construction of the facility.

The University of South Carolina is a leader in alternative energy research, particularly hydrogen fuel cells, next-generation nuclear energy fuels, solid-oxide fuel cells, and energy efficiency and conservation. The University's investment in its biomass energy facility and ongoing energy infrastructure improvements is part of the institution's long-term commitment to energy conservation and renewable energy use.



Chris Toumey

Forums on Our Energy Future

The Citizens' School of Fuel Cell & Hydrogen Technology prepares the general public for participation in policy-making related to science and technology.

To help citizens gain a better understanding of the United States' energy options and the ramifications of its choices, the College of Engineering and Computing is sponsoring five public forums across South Carolina, which began this spring.

Forums on Our Energy Future focus on nuclear power (April 30 at USC Aiken), coal (May 14 at Florence-Darlington Technical College), hydrogen (June 4 on the Columbia campus), renewable energy (June 25 at USC Upstate), and energy conservation (July 23 at Claflin University).

"Our energy resources in the years ahead will draw from multiple materials and technologies," said Michael Amiridis, dean of the College of Engineering and Computing. "Coal, nuclear, and hydroelectric will probably be accompanied by solar, wind, ethanol, hydrogen, biomass, and other forms, and we need to discuss how these different forms will each have a role."

The forums will feature presentations from knowledgeable representatives for each form of energy, followed by an alternative response from another group. Because this is a presidential election year, representatives from the Democratic and Republican parties will also offer responses reflecting the views of their respective parties on the energy form discussed.

"It's our hope that people who attend these forums will acquire a better understanding of the relevant science and technology policies associated with each of these forms of energy," said **Chris Toumey**, a research associate in the College of Engineering and Computing who organized the energy forums.

Toumey also helped establish the Citizens' School of Fuel Cell and Hydrogen Technology, which held two sessions in 2007 and another this spring. The school, which offers seven- to eight-week sessions, was funded by the S.C.

Wind energy accounted for 1 percent of total worldwide energy production in 2005; it accounts for 20 percent of Denmark's electricity consumption.

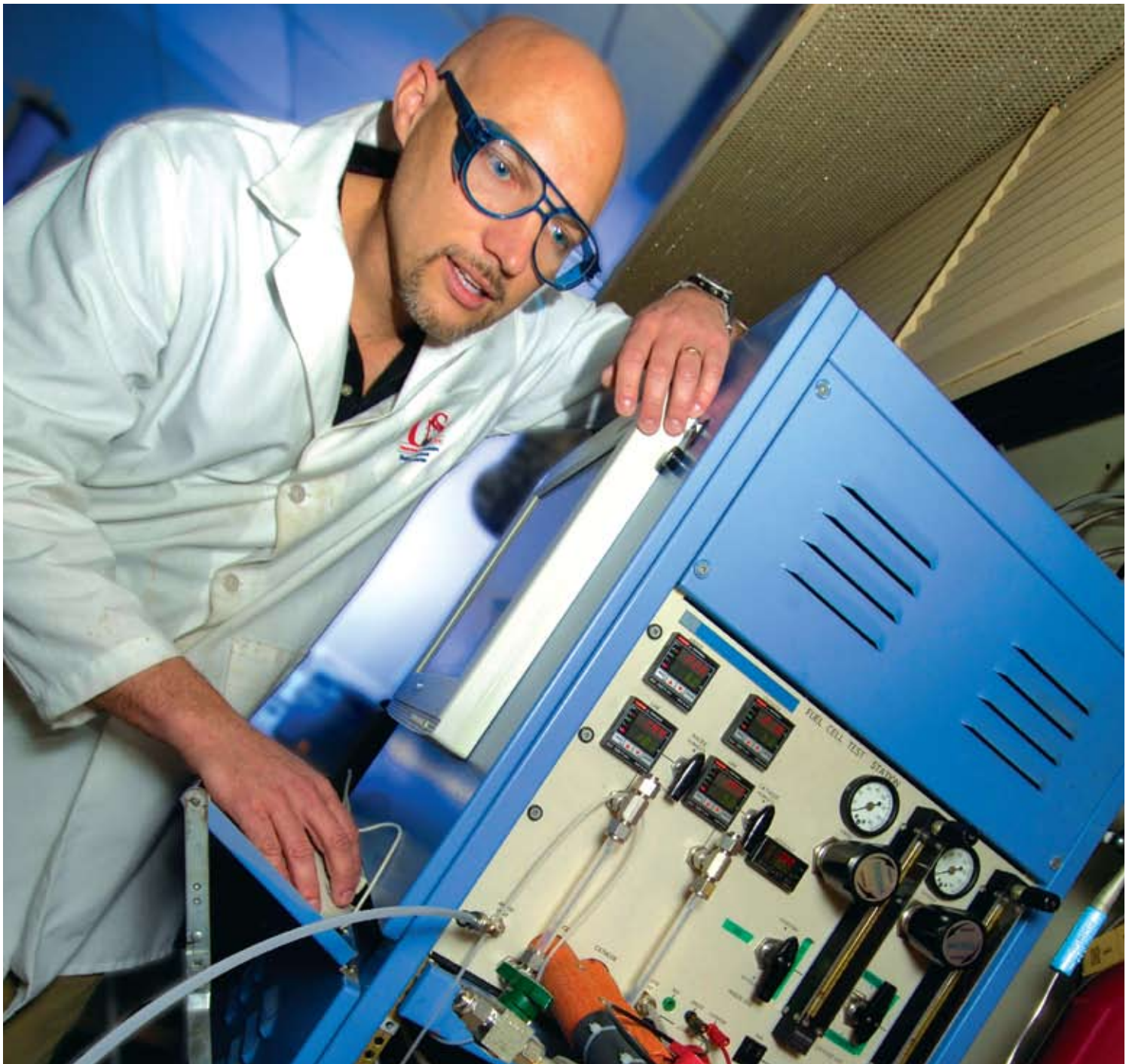
ENERGY FYI

Research Authority and the Greater Columbia Fuel Cell Challenge with a matching grant from the University's Research and Health Sciences division.

"If non-experts are going to be engaged in any kind of science and technology policy—as they should be—it really has to be in a dialogue format," Toumey said.

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The gas engine in a typical car is less than 20 percent efficient in converting gasoline into power. Hydrogen fuel cell vehicles operate with a 40-60 percent efficiency rate.

ENERGY FYI



World-class research in fuel cells

The University of South Carolina's Center for Fuel Cells helps build the road to a hydrogen economy.

When the University of South Carolina's Center for Fuel Cells (CFC) unveiled a hydrogen fuel cell-powered Segway last year, the futuristic two-wheeled device helped turn seemingly abstract research into concrete reality that nonscientists could understand.

"Our challenge was to get fuel cells out in front of the public and demystify those devices," said **John Weidner**, opposite page, professor of chemical engineering and a researcher in the CFC. Weidner and his colleague **Chuck Holland**, an engineer in the University's Department of Chemical Engineering, modified the Segway so that its batteries could be continuously charged by a hydrogen fuel cell. The vehicle demonstrated a practical application of the hydrogen fuel cell and symbolized the important research being conducted at the CFC.

With an internal grant from the vice president for Research of Health Sciences, Harris Pastides, the CFC opened its doors in October 2001. Two years later, it became a National Science Foundation-Industry/University Cooperative Research Center (NSF I/UCRC) for Fuel Cells—the first and only one of its kind in the nation. Even though many cooperative research centers in various fields were already in place around the country, the NSF selected South Carolina's College of Engineering and Computing to work with industry and help lead the nation's fuel-cell initiatives.

"The University of South Carolina's strong history of world-class research in fuel cells—even before fuel cells were thought to be 'exciting'—and our demonstrated ability to work successfully with industry were the decisive factors in landing this center in Columbia," said **Michael Amiridis**, dean of the University's College of Engineering and Computing.

Associated with the CFC are several Centers of Economic Excellence, such as the Center of Economic Excellence in solid-oxide fuel cells, or SOFCs. Additional centers—one each for fuel-cell sensors, hydrogen storage, and catalysis—are being formed, with the three endowed professorships already approved. Fuel cells, like the modified Segway, are going places.

The promise of hydrogen

A fuel cell is a device for producing electrical power by way of an electrochemical reaction between hydrogen and oxygen, not through combustion as with fossil fuels. Various kinds of fuel cells exist, but they all rely on the same basic components: a positive cathode, a negative anode, a catalyst, and an ion-conducting electrolyte sandwiched between the two electrodes. If the application calls for AC power, a power conditioner converts the fuel cell's direct current to alternating current. Because single fuel cells produce only a limited voltage each, they are usually stacked to meet higher power needs.

"In general, fuel cells allow us to store energy very economically," Weidner said. Today, electrical batteries are the only practical means for storing energy. On a small scale, they work fine, but on a larger scale—say at the power-plant level—they're not very effective. Fuel-cell "batteries," on the other hand, could help level loads in power generation, for example, by supplying additional power when demand is high, and storing power when the demand is average or low. Relying on fuel cells could reduce our need for more or larger power plants to handle peak loads.

The technology holds numerous potential applications. For example, we could someday run our appliances using fuel cells and use the excess heat for hot water in our homes. Fuel cells could power our laptop computers and other personal electronics with a much longer battery life. And, of course, fuel cells can give us completely different types of cars.

In fact, the devices can already be found in some cellular-telephone towers to provide backup power when ice storms or hurricanes disrupt electrical power service. And fuel-cell companies are selling forklifts with fuel cells, eliminating the problem of downtime when batteries need to be recharged or swapped out.

Hydrogen produced by splitting water with sunlight represents the ultimate carbon-neutral renewable fuel, and this technology requires research. In the short term, wind power, the conversion of natural gas, and nuclear power will prove to be hydrogen's ideal partners as we move toward an economy that relies on sources of energy less-polluting than fossil fuels.

"One reason people want to move to a hydrogen economy is to reduce our dependence on foreign oil," said **John Van Zee**, professor of chemical engineering and director of the CFC. "A lot of them see it as a matter of energy security." The second reason for moving to a hydrogen economy, he said, is the need to reduce our impact on the environment.

The technology has its critics, of course. "There are many who argue against a hydrogen economy, citing present-day costs to produce hydrogen and the challenges of transporting hydrogen gas," Van Zee said. "They're wedded to a fossil-fuel technology, a technology that cannot be sustained over the long term, and that is why we do research."

The center's federal funding sources contradict much of the criticism—the NSF, the Department of Defense, and the Department of Energy (DOE) are clearly interested in exploring hydrogen's promise.

Working with industry

The NSF I/UCRC was formed specifically to work on pre-competitive research for industry—research that is generally cooperative and has broader applications than a single company's product line. The center has interacted with 24 industrial partners since its inception, and partners may come and go as their corporate needs and priorities dictate. "They pay dues, and we work on their projects," Van Zee said.

The CFC enjoys international connections, too. It has an agreement with the Korea Institute for Energy Research, and the center exchanges professors and students with the Fraunhofer Institute in Freiberg, Germany.

The research

The CFC represents the first major effort carried out within the Future Fuels™ scope of research. Future Fuels is the University's active research program focused on bringing about a clean, energy-efficient future.

Even though many different substances could serve as fuels, the DOE has shown a particular interest in hydrogen because of its diversity, its ability to be generated using various sources

ENERGY FYI

A coal- or natural gas-fired power plant generates electricity at an efficiency rate of about 35 percent; a fuel cell system can generate electricity with up to 60 percent efficiency.

Hydrogen: An energy carrier

Fossil fuels such as coal, oil, and natural gas are known as primary sources of energy because they actually constitute solar energy stored eons ago in plants that absorbed the sun's rays. When the plants died, time and geological processes transformed them into the fossil fuels we rely on today.

Hydrogen, even though the stuff of stars, does not embody solar energy. And abundant as it is, hydrogen does not exist naturally in free form here on earth but appears only in compounds. Hydrogen atoms must therefore be split from the atoms of other elements before the gas can be put to productive use. Those atoms can be extracted from water (through electrolysis) or from a fossil fuel (through a process called reforming). Both processes call for another source of energy to make them work, and that reliance explains why hydrogen is not considered a primary source. Solid-oxide fuel cells require less reforming than other types, and, for some fuels, they need little or no reforming.

Hydrogen serves as an energy carrier—a means for taking energy from a primary source and giving it greater versatility, just as electricity does. That's where fuel cells come into play.

"Fuel cells are not about where energy comes from," said **Ken Reifsnider** of the University's Solid Oxide Fuel Cell Program; "they're about how we use energy. They're energy conversion devices."

At a coal-burning power plant, for example, we take energy from coal and convert it—by means of a turbine-generator—into electricity to use as a "fuel" for operating the appliances in our homes far away. The electricity "carries" the energy produced by the coal to where it's needed. Similarly, we can take biomass and turn its energy into hydrogen fuel for our fuel cell-driven cars. And, as with electricity, we can store hydrogen for later use.

In a hydrogen economy, hydrogen and electricity work side by side. "For many applications, electricity will still be what you want," said **John Weidner** of the Center for Fuel Cells, "and there's no better way to convert hydrogen to electricity than through a fuel cell. If we move to a hydrogen economy, the fuel cell will have to be part of it."

of energy, including renewable and sustainable sources such as biomass, solar power, and wind power.

The CFC has focused on proton-exchange membrane fuel cells, or PEMFCs, and direct-methanol fuel cells, or DMFCs. "Those two types were our strong suit," Van Zee said, "but, with new faculty, we will include SOFCs." The center exists to help industry advance the technology and commercialization of fuel cells by performing research in five areas: fuel-cell design and software; fuel-cell performance experiments; hydrogen storage materials; catalysts for hydrogen production and electrodes; and motor design and power conditioning.

"Where we excel is in our ability to understand how each component of a fuel-cell system affects the big picture, the entire value chain," Van Zee said. "You have to understand the interactions among all of the components and operations in a fuel cell to lower the cost and improve performance," he said. "You can't focus on just one part and ignore the rest."

Two major challenges impede fuel-cell commercialization at this time. One is cost: Fuel cells today are expensive because people build them in ones and twos—the devices are not yet mass-produced. The other challenge is finding the right balance between cost and lifetime. "We can design a fuel cell with the most expensive components that will last a very long time," Van Zee said, "but that's not the intent. We have to design it so people can afford it."

The quest for affordable, highly efficient fuel cells is keeping Van Zee and his colleagues busy, and they're certainly making progress. "But a large part of our effort is educating scientists and engineers for this next generation of power devices," Van Zee said. "As professors, we find that equally enjoyable." ■

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Jim Ritter

Hydrogen storage

The challenge of building a hydrogen fuel cell-powered car is difficult enough. An equally important task is developing technology for storing hydrogen—a highly reactive and volatile element.

University of South Carolina scientists are immersed in Department of Energy-sponsored research to find the best ways to do that.

"There are only three options for storing hydrogen," said **Jim Ritter**, a chemical engineering professor at South Carolina. "You store it as a gas at high pressure in expensive, carbon fiber-wound tanks. You can liquefy it by refrigeration but only at very low temperature. Or you store it at lower pressure in a conventional tank by putting solid particles in the tank that can absorb the hydrogen gas and release it when it's needed."

Ritter, postdoctoral associate Marjorie Nicholson, and others on his research team have focused on the latter approach, developing a powdery material made of sodium, lithium, aluminum, and boron hydrides that can cycle and absorb and release hydrogen gas.

Using metal hydrides to absorb hydrogen allows storage of the gas at relatively low pressure—100-200 psi (propane gas for an outdoor grill is stored at about 130 psi)—in a relatively light-weight tank. Without the metal hydride particles inside, a hydrogen storage tank would have to be specially designed to accommodate the 5,000-10,000 psi pressure now being considered.

Ritter has three patents pending on the hydrogen storage research, but says the challenges of hydrogen storage remain daunting.

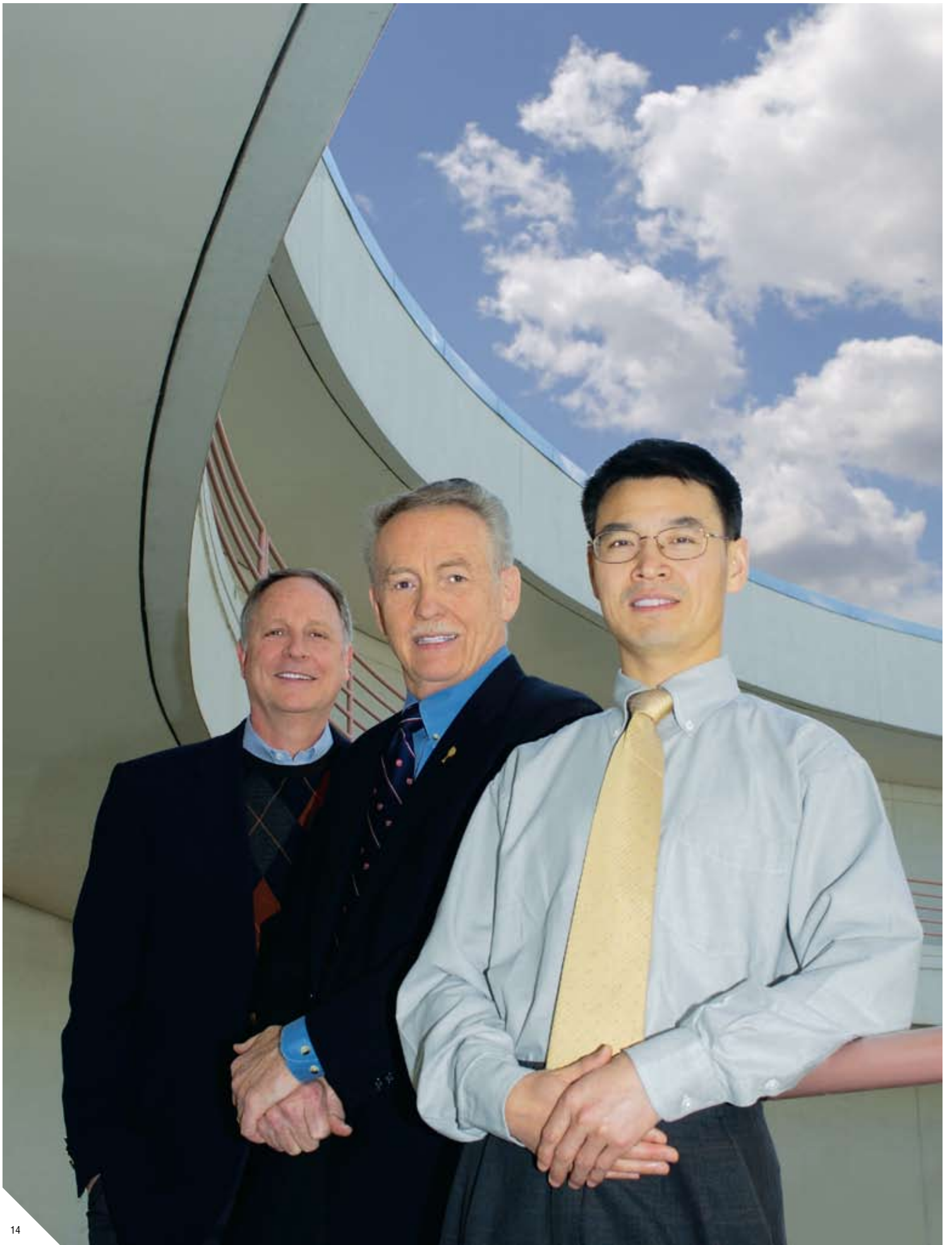
"The metal hydrides we've developed don't hold a lot of hydrogen and need about 1,200 psi of pressure in the tank. They work well for large stationary units, but not for smaller, portable tanks that would be required for an automobile," he said.

In fact, none of the hydrogen-absorbing materials developed in research labs across the country have been able to meet fully the goals of industry for hydrogen storage capacity and cycling requirements.

"As things stand now, we've got the technology to store hydrogen on large equipment—big trucks, locomotives, or forklifts where the size or weight of the tank doesn't matter," Ritter said. "The challenge of building an economical and lightweight hydrogen storage tank for an automobile is largely unsolved. But it will be."

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Low-emission, high-efficiency energy conversion

With a focus on energy demands and the environment, the University of South Carolina's Solid Oxide Fuel Cell Program is developing a highly versatile way to produce electricity.

"Science makes things possible; engineering makes them work," said **Ken Reifsnider**, Educational Foundation University Endowed Professor of Mechanical Engineering and director of the Solid Oxide Fuel Cell Program. "Our mission is engineering."

The former director of the Connecticut Global Fuel Cell Center at the University of Connecticut, Reifsnider brought his expertise to the University of South Carolina last summer and now holds the distinction of being the only active member of the National Academy of Engineering in the state. "We're very fortunate to have Prof. Reifsnider joining us," said **John Van Zee**, director of the Center for Fuel Cells. "His addition to the faculty really speaks to the growth in fuel-cell research at the University."

Reifsnider specializes in solid-oxide fuel cells (SOFCs), a kind that relies on a solid ceramic electrolyte rather than on a polymer that's used in proton-exchange-membrane and direct-methanol fuel cells. The ceramic electrolyte allows the fuel cell to operate at high temperatures, 700–800 degrees Celsius, a characteristic that eliminates the need for a reformer for some fuels. That elimination means the SOFC can run on various kinds of hydrocarbon fuels, not just on reformed hydrogen.

SOFCs offer the greatest energy-conversion efficiency compared to other fuel cells and standard means of producing electricity because they convert fuels directly into electricity at high temperature without combustion, and they involve no moving parts as do turbine-generators. Making the most of that high efficiency forms an essential part of the program's mission.

"We're working on a fundamental understanding of how to make new electrode materials that are more active, thereby giving us a better performance," said **Frank Chen**, an assistant professor with the program. "We're studying the different operating parameters and asking, 'How can we make the fuel cell work more efficiently?'"

Industry is working on the balance-of-plant engineering aspects—all of the associated components needed to put SOFCs to productive use in an actual industrial application. That effort includes the need to minimize the energy input required to make the fuel-cell system work, allowing for maximum efficiency. South Carolina's SOFC program then integrates industry's findings into its own research. "That's what makes this center unique," Chen said.

Like other fuel cells, SOFCs do a good job of converting stored energy such as hydrogen gas into electricity. That makes SOFCs a great complement to alternative energy sources such as solar power and wind power. When the sun isn't shining or when the wind dies down, an SOFC can kick in and continue electric generation without interruption. Even better, fuel cells can convert stored energy into electricity more economically than standard batteries, and the potential applications are numerous, from cell phones to trains and ships.

"Solid-oxide fuel cells have been around for decades," Reifsnider said, "but we are focusing on new systems that will allow us to do things for our society that we have not been able to do before."

From left, John Van Zee, Ken Reifsnider, and Frank Chen work in the University's Center for Fuel Cells.

On a smaller scale, SOFCs are even being used to power cell phones and laptop computers, and to provide auxiliary power.

Energy serves as the impetus for the strong focus on SOFCs: energy availability, the need to reduce our reliance on nonrenewable resources; and energy security, the need to wean our nation off foreign oil. Another driver is the environment—not just inherently environmental concerns, but economic considerations.

"The environment has become an incredibly important feature of our international economy," Reifsnider said. Major investors around the world have expressed great interest in SOFC technology.

When it comes to this technology, Reifsnider said, it's not a matter of when it's going to happen; it's already happening.

Taiwan, for example, already has a national SOFC program; the United States doesn't. "The only questions now are how is it going to happen and who is going to pay for it?" he said. "Are we going to buy the technology from somebody else, or are we going to develop it here in the United States?"

Chen agrees. "This technology's success depends on whether people have the mindset to invest in it," he said. "If the United States doesn't invest in this leading technology, if we don't play a dominant role in it, we will miss a great opportunity." ■

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California plans to have 50 to 100 hydrogen fueling stations in place by 2010.

Waiting for the bus

Hybrid-electric transit bus will be tested in Columbia later this year

When a hybrid-electric fuel cell transit bus begins rolling through the streets of Columbia, S.C., this fall, **Tom Davis** will be ready to climb on board and start collecting data.

The chemical engineering research professor is looking forward to seeing how the new bus—part of the Federal Transit Administration's Fuel Cell Bus Program—performs on Columbia's hilly streets.

"Columbia was chosen for this demonstration project because of its heat, humidity, and hills," said Davis, who conducts research on several aspects of hydrogen energy. "It's not because we're an easy site—quite the opposite."

The 37-passenger bus body is built of fiber composites and is five tons lighter than a regular transit bus. Powered by two 16kW fuel cells that will continuously charge a battery pack, the bus' performance will be measured for acceleration, braking, and operating range during its one year of operation in Columbia.

"We'll have a GPS system on board, so we can determine within a few feet exactly how it was performing going up and down hills and all along the route," Davis said. "The bus will run on two routes for the Central Midlands Regional Transit Authority and on one route for the University of South Carolina."

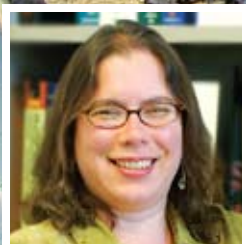
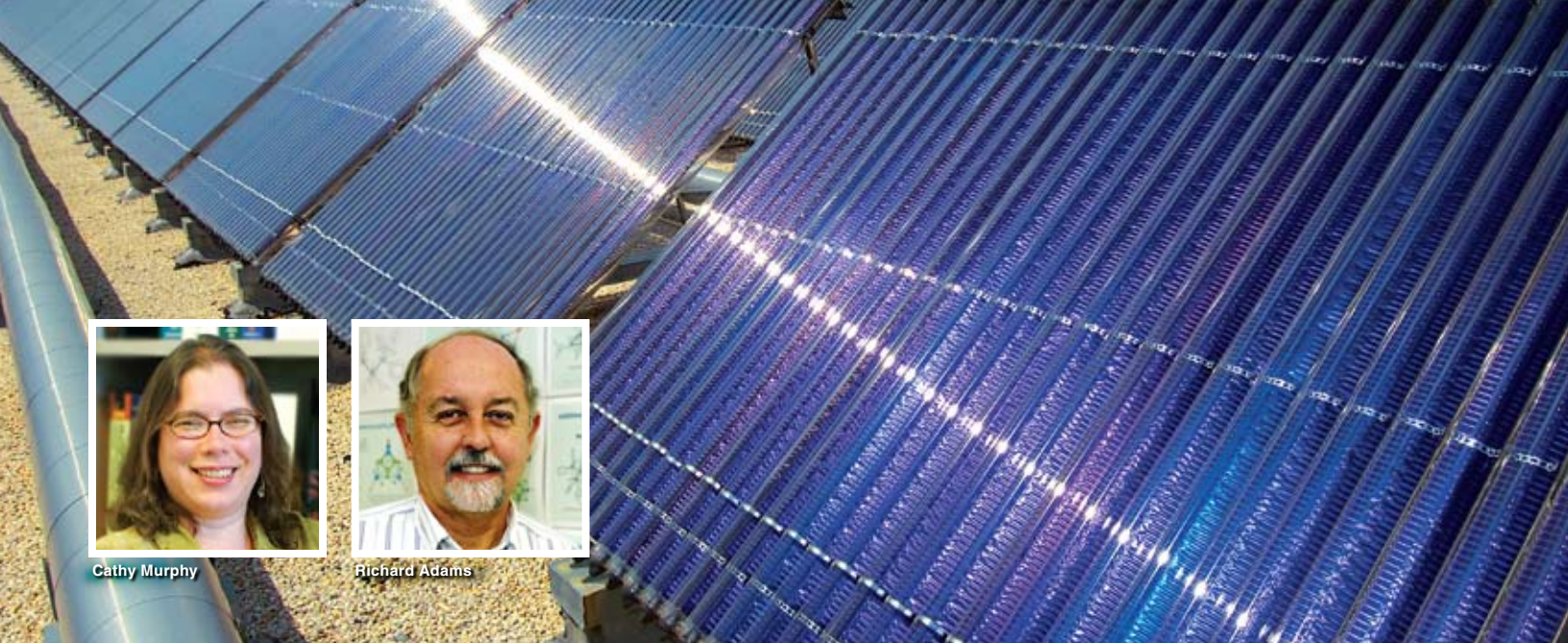


The demonstration project is aimed at proving the capability of a hybrid-electric fuel cell bus and stimulating economic competitiveness in fuel cell bus technologies. The goal is to develop a bus that will double the fuel efficiency of a comparable diesel-powered transit bus while achieving the same or better performance measures.

Davis and other University researchers have consulted with the S.C. Research Authority, which is managing a project to build a \$2.4 million hydrogen fueling station in Columbia for the demonstration bus. The station will also serve hydrogen-powered vehicles that will visit the city in April 2009 when the National Hydrogen Association holds its annual meeting in Columbia. The cost of the fueling station is being funded by the State Hydrogen Infrastructure Fund.

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Cathy Murphy



Richard Adams

Solar gain

Renewable energy from the sun is getting a boost in solar cell research at South Carolina.

The earth receives more energy from the sun in one hour than the world uses in one year.

ENERGY FYI

The golden rays of the sun are getting a little help from nano-sized particles of gold in a Department of Energy-sponsored research project on solar cells.

Two South Carolina chemistry professors are developing the special nanoparticles in their labs that could improve the light-gathering and electricity-generating efficiency of hybrid organic/inorganic solar cells.

Cathy Murphy and Richard Adams are collaborating with Wake Forest University physicist Dave Carroll on a three-year, \$810,000 grant sponsored by the Department of Energy. The grant is one of 27 funded by DOE from a pool of more than 600 proposals; all are related to solar energy research.

"Solar cells still are not cost effective for large-scale use," Adams said. "But if they were more efficient, large-scale applications would make more sense. There is a lot of solar energy, but it is fairly dilute—that's why we need to improve the efficiency of solar cells."

Murphy is developing silver and gold nano particles—shaped like tiny rods—that improve the absorption of visible light and amplify its effects. "You can

tune the wavelength of light absorbed by changing the size of the nanorods," Murphy said. "A single layer of these silver or gold nanorods in the solar cell is all that's needed to get the improvement."

Adams is developing metal sulfide nanoparticles that aid in creating photo-currents from the gathered solar energy. Carroll, their Wake Forest University collaborator, will load the nanoparticles into solar cells, which will be tested at the National Renewable Energy Laboratory in Golden, Colo.

The team plans to have a working solar cell model before the grant expires.

"I think we have a good chance of making some improvements to the existing technology for solar cells," Adams said. "If we can help improve their efficiency, we'll have made a worthwhile contribution."

To further its research on photovoltaic energy, South Carolina is recruiting a cluster of faculty in chemistry, mechanical engineering, and electrical engineering who will concentrate their research in this area. The cluster hire, which will be funded through the University's Faculty Excellence Initiative, is expected to bring

one or two faculty members to campus by this fall with more to follow.

"We anticipate exploring broad uses of solar energy and looking at combined photovoltaic and thermal systems," said Roger Dougal, an electrical engineering professor who is chairing the search for the cluster recruitment. "The heat from a solar panel is low grade and usually thrown away, but it could be used in residential or commercial systems for hot water and space heating or with thermoelectrics to produce additional electric power."

To get students interested early on about photovoltaic research, the College of Engineering and Computing offered a course on photovoltaics during the winter interim session at the Governor's School for Science and Mathematics, a special high school for gifted students in Hartsville, S.C.

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Conservation and efficiency

Two South Carolina researchers are finding ways to inject new energy efficiency into old technology.

In any discussion of alternative energy and future fuels, the lowly internal combustion engine doesn't command much respect.

True, the gasoline engine was the transportation workhorse of the 20th century, but it's also branded as a major culprit in global warming. Can this dinosaur of transportation technology play a role in future energy solutions?

Mechanical engineering professor **Abdel Bayoumi** thinks so. In fact, he hopes to teach the old dog—internal combustion engines—a new trick: using hydrogen gas instead of gasoline or diesel fuel.

"BMW started doing research on this 10 or 15 years ago but stopped when fuel prices bottomed out a few years ago," Bayoumi said. "We've met with them recently, and there is a lot of interest in reviving this research. We already are working with Siemens, which makes diesel injectors, to adapt an injector for hydrogen use."

The challenges of developing a full hydrogen economy—hydrogen fueling stations on every corner, for example—are steep, and even the most optimistic hydrogen fuel cell enthusiasts predict it will be many years before significant numbers of cars use that technology. The hydrogen-injected internal combustion engine is an intermediate step, Bayoumi said, that doesn't require such a quantum leap in infrastructure and research development.

"We have a century of research and development on the internal combustion engine. This would require making adaptations to use a different type of fuel, which is a significant but not insurmountable task," he said.

The most immediate market for hydrogen-injected engines would be medium- to large-size trucks, which account for 70 percent of total fuel consumption in the United States. Those trucks, which largely travel on interstates and primary highways, wouldn't need hydrogen fuel stations everywhere like automobiles do.

"If there was not an energy crisis, I would say put all of the research effort into fuel cells," Bayoumi said. "But we need an intermediate step, a bridge to get us to that point. We're already doing something similar by using biodiesel in internal combustion engines. This is just another way to adapt the i/c engine to emerging technology."

A new light

Asif Khan, an electrical engineering professor, sees dollar signs every time he looks at traditional incandescent lights. That's because the lightbulb Thomas Edison invented is not particularly efficient at converting electricity into light. Newer, solid-state lighting, which uses light-emitting diodes, could reduce America's electricity needs by 30 percent if adopted wholesale, Khan said.

"Imagine how many power plants could be eliminated," said Khan, whose research group is considered among the top two in the country for developing new materials for solid-state lighting.

Khan's research group, which includes scientists **Tom Katona**, **Krishna Balakrishna**, and **Vinod Adivarahan**, has focused much of its efforts on developing materials that can produce colored light. Up until the 1990s, the materials available for solid-state lighting could emit only red light or infrared light—no green or blue. Khan's team was one of the first to begin the search for materials that could emit green and blue light.

The results are visible at almost any updated traffic light: bright LED hues of red, yellow, and green that are not only brighter and safer but also far more energy efficient.

Khan's team also is studying gallium-indium-nitride, an exotic alloy of materials whose strength and high-temperature resistance makes it a good candidate for use in solar cells and high-voltage switches in electric cars and other applications.

"There are lots of problems that our research must overcome," Khan said. "How do you make uniform deposits of the material on solar cell panels and how you change the optical properties of the material to absorb the most light? We're working on those questions."

Khan is confident of success and so, too, is the University, which owns a portion of a company he has formed (Lightec Inc.) to commercialize the emerging technologies. Now in the University's Technology Incubator, Lightec already is growing. ■

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Michael Amiridis

Clean Coal

New technology could make coal a major player on the list of clean energy sources.

The phrase 'clean energy' usually conjures up images of giant windmills and massive solar panel farms, churning out voltage without a whiff of CO₂ or any other greenhouse gas.

But one of America's oldest, dirtiest, and most plentiful fuels could join the clean energy club if research efforts can provide the needed technology.

The electricity used by the average person in the United States each year requires 3.8 tons of coal.

"The United States has coal reserves for the next 300-400 years, and they're going to be part of the energy mix," said **Jim Ritter**, a chemical engineering professor at the University of South Carolina. "But to do that without creating more greenhouse gases, we have to develop clean coal technology."

South Carolina is aptly positioned to make clean coal a reality with the establishment of its Center of Excellence in Clean Coal Research. The center is funded

by \$5 million from the state of South Carolina and \$5 million from the Electric Cooperative of South Carolina and Santee Cooper, the large state-owned electric utility that produces electricity primarily from coal-fired generating plants.

Most of the funds will be endowed to provide sustained support for the center, while some also can provide immediate direct support of carbon removal research (the greenhouse gas CO₂ is a major emission from coal-burning power plants).

"As the state's leading electricity provider, we understand our role in spearheading initiatives to help us balance the demand for increased electricity with our environmental responsibilities," said **Lonnie Carter**, Santee Cooper president and chief executive officer. "Carbon removal technology will be essential as we move forward. We are confident that this enterprise will yield significant improvements that will showcase South Carolina as a leader in the critical discussions to come."

Producing electricity from coal-fired steam turbines is an important part of the energy equation in the United States—about 500 such plants generate

about half of the country's electricity. But it hasn't been without consequences: acid rain and greenhouse gases are two of the byproducts of burning coal.

"CO₂ is not a pollutant, but it's a greenhouse gas that we have to capture," Ritter said. "We're looking at pressure swing adsorption models that would capture the CO₂ as it's going up the stack."

"The problem is that it requires very high heat and uses up to 30 percent of the plant's energy output to capture the carbon. Then you have to do something with the CO₂, either compress it or liquefy it or pump it deep in the ocean or underground."

Five years ago, the Department of Energy announced plans for FutureGen, a prototype for next generation coal-fired generating plants. The demonstration project would have produced electricity and hydrogen gas from coal placed in high-temperature gasification vessels. In February, DOE pulled the plug on FutureGen—the price tag had nearly doubled to \$1.8 billion—but the agency remains committed to funding development of carbon-capturing equipment at commercial coal power plants. Some energy policy analysts say that could actually speed up the technology process for making clean coal a reality.

"This country hasn't been devoting enough research to coal, so it's been challenging for us to find an endowed chair for our clean coal center—the field is very limited," said **Michael Amiridis**, dean of the College of Engineering and Computing. "We might have to go outside the United States to Canada, England, or Australia, all of which have stronger research efforts in coal."

The important thing, Amiridis said, is that political will is strong to find a clean coal solution. And with funding and scientific perseverance, it can be developed, he said.

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Clean cut

In his undergraduate research at the University of South Carolina, Solomon Addico is learning all about being "green" while maintaining a green lawn. A Ronald E. McNair Scholar, Solomon is working with mechanical engineering professor Wally Peters to study the environmental impact of electric, solar-powered, and gasoline lawn mowers. His research findings were presented last summer at the McNair Scholars Research Conference in Knoxville, Tenn., and Solomon is looking forward to one day sharing his love for science as a teacher.

At the University of South Carolina, we believe in undergraduate discovery for every discipline, and we support it through our Office of Undergraduate Research, our Magellan Scholars Program... and through hundreds of students like Solomon who are expanding their horizons through faculty-mentored research.



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